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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

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A novel pull-in procedure in air gap servo system for near-field optical recording

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A Novel Pull-in Procedure in Air Gap Servo System for Near-Field Optical Recording

Abstract of the invention

This invention describes a new pull-in procedure in the air gap servo system for near-field optical recording. The new pull-in procedure has two features; (i) a sinusoidal excitation for the approach control to guarantee a zero velocity when the air-gap servo system starts its closed-loop operation and (ii) the 2 degree-of-freedom (DOF) control technique for the hand-over control to relax the design constraints between the overshoot and the settling time.

1. Introduction

An optical recording using a near field optical head, which consists of an aspherical lens and a Solid Immersion Lens (SIL), has been proposed as a technology to read out 50 Gbyte or more on a 12 cm disc. In this system, it is essential to maintain an air gap between the SIL bottom surface and the disc constantly in a near field position where the evanescent wave is detectable.

A schematic diagram of our experimental near field player set-up is shown in Fig. 0. In the player we use a conventional Philips DVD actuator for air gap control and tracking in which we mounted the NA = 1.9 lens.

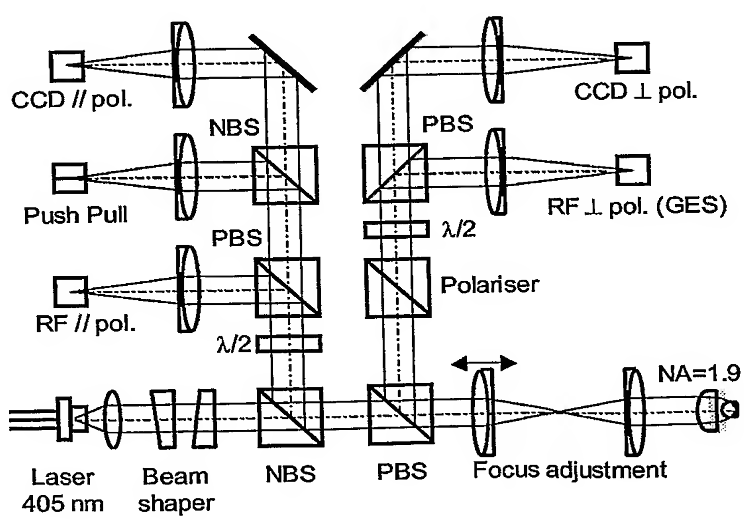


Figure 0. Schematic of near-field recording player setup (PBS=Polarizing beam-splitter; NBS=Non-polarizing beam-splitter; $\lambda/2$=half-wave plate)

The set-up consists of a main branch comprising a blue-violet laser, collimator lens, beam shaping optics, two beam-splitters and a telescope for focus adjustment of the NA=1.9 lens. The

left side branch in the figure contains a photodiode for detection of the RF central aperture signal that contains the data information and is polarized parallel to the main beam ("RF // pol."). In the same branch a split detector is positioned to generate a push-pull tracking error signal. Moreover, a CCD camera is included to observe the irradiance pattern at the exit pupil. The half-wave plate is used to control the amount of light that the PBS splits and directs towards the RF detector and the push pull detector, respectively.

The second branch on the right side is used to generate the error signal for air gap control. In near field optical disk systems, the SIL lens needs to be positioned within the evanescent decay distance from the disk. In our set-up the SIL to disk distance is typically 25 nm. To allow air gap control with a mechanical actuator at such small distances, a suitable error signal is required. As demonstrated by Ishimoto [1] and Saito [4], a linear signal that is suitable as a gap error signal (GES) can be obtained from the reflected light with a polarization state perpendicular to that of the main beam that is focused on the disk. A significant fraction of the light becomes elliptically polarized after reflection at the SIL-air-disk interfaces: this effect creates the well-known Maltese cross when the reflected light is observed through crossed polarisers. By integrating all the light of this Maltese cross using polarizing optics and a single photodetector, the "RF ⊥ pol." signal is obtained. The GES is generated from this "RF ⊥ pol." signal. In Fig 1, we show the calculated reflection curves for the parallel (//) polarisation, the perpendicular (⊥) polarisation and the sum (total) as a function of the air gap width.

The amount of the perpendicular polarization state of light reflected at the bottom of the SIL has been proposed as a gap error signal (GES) to control the air gap [1]. Unfortunately, however, this gap error signal is available only within a near field regime of approximately 50nm as can be seen in the figure 1.

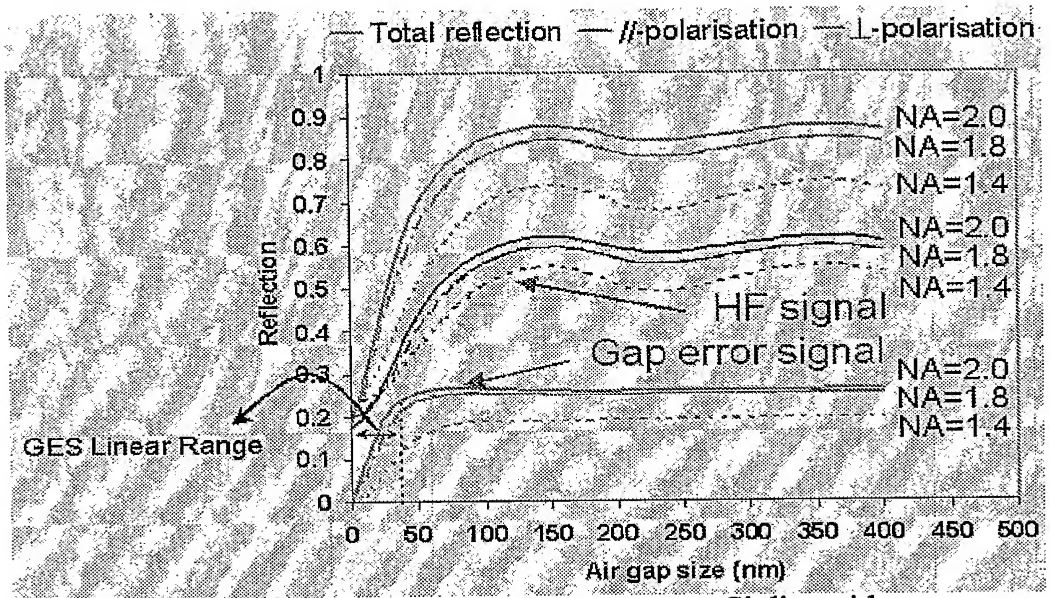


Figure 1. Simulated GES curves on Si disc with no grooves

Therefore, the so-called pull-in procedure has been proposed in [1]. By the pull-in procedure, the optical head approaches the near-field regime from its initial far-field position through an open-loop operation, and then the air gap servo system is switched into a closed-operation as smooth as possible to avoid any collision of the optical head with the disc.

In this prior art, as is shown in the figure 2 below, a ramp voltage was applied to the biaxial actuator. This leads to a constant approaching velocity at the switching instant when air gap servo system starts its closed-loop operation. However, if the air gap servo system is digitally implemented, in order to avoid any collision of the optical head with the disc at the switching moment, one condition shown in the figure 2 should be met between the approaching velocity, the GES linear range, and the sampling period Ts. For instance, if the approaching velocity is 5 mm/sec and the sampling period is 20usec, then the optical head can travel 100nm, which is twice the GES linear range, during one sampling period. Therefore, in this case, either the approaching velocity should be made slower or the sampling frequency should be made higher.

On the other hand, when the optical head enters the near-field regime and hence the air gap servo is switched into its closed-loop operation, the gap reference for the gap servo loop is not set to its final target value (Ref2), but it is gradually lowered to its final value over a fixed time interval, which is referred to as 'settling time'. In this way, as can be seen in figure 3, the air gap servo system can start its closed-loop operation without colliding of the optical head with the disc. However, as was shown in [1], there exists a design trade-off between the settling time and the overshoot, which can limit the overall pull-in performance.

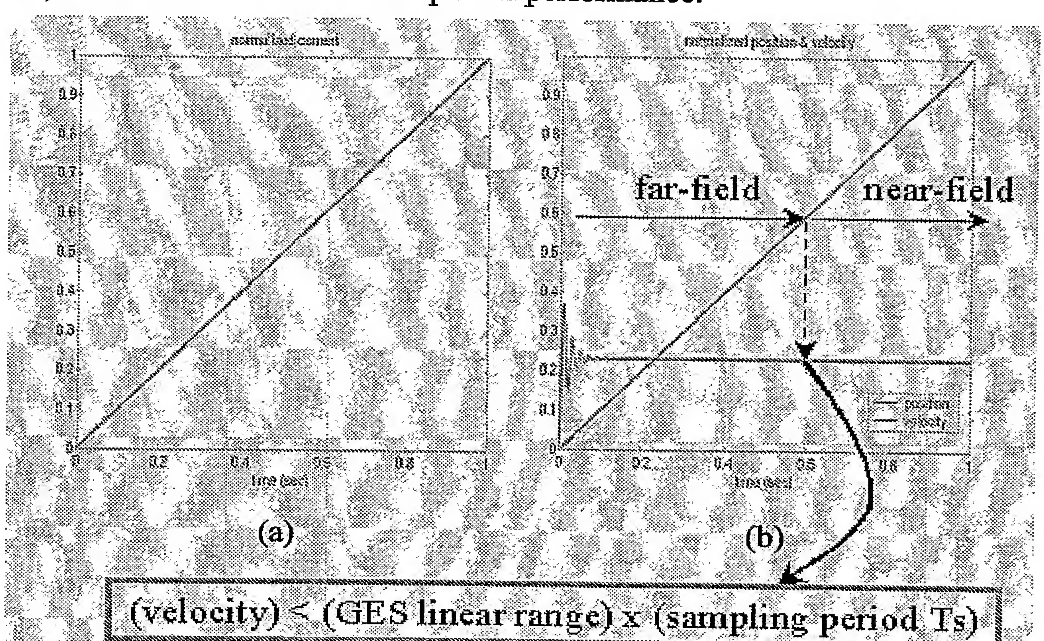


Figure 2. Prior art: approach method by ramp voltage
((a) applied current for approaching (b) position & velocity during approaching)

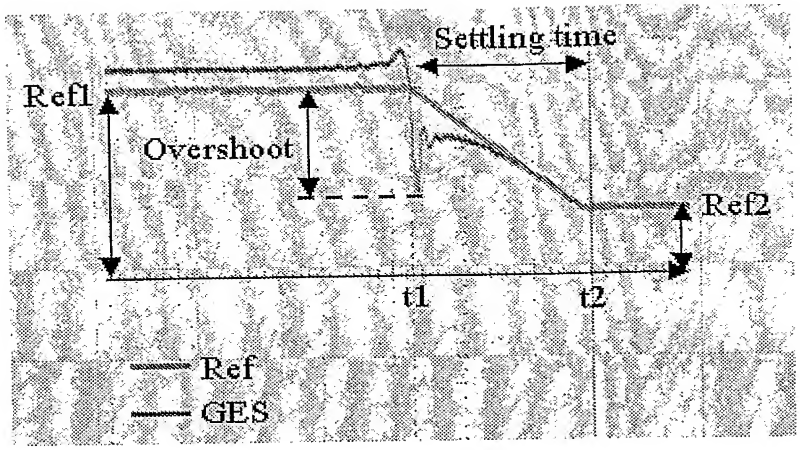


Figure 3. Prior art: pull-in response

2. New Pull-in Procedure

First, the figure 4 presents the schematic diagram of the proposed air-gap servo system, which can be referred to as the mode-switching control because three different control structures are, depending upon the operating condition, switched from one to another during the whole servo action [2]. Precisely speaking, the approach control is to move the optical head from its initial far-field position into the near-field regime where the linear GES is detected; the hand-over control is to achieve a smooth and fast transient response during the switching from the open-loop approach control into the final closed-loop air gap regulating control; and finally the air-gap control is to maintain the air-gap around a fixed target air gap. Here, the pull-in procedure is defined as the combination of the approach control and the hand-over control.

Now, the new pull-in procedure will be explained.

First, in the approach control mode, instead of the ramp signal as in the prior art, a sinusoidal signal with its amplitude increasing over time is applied to the actuator as shown in figure 5(a). Assuming that the actuator is modeled as a 2nd order mass-damping-spring system, we see that the corresponding position and velocity behaviors are also sinusoidal with the amplitude increasing over time. Then, as is shown in the figure 5(b), at some point in time $t=t_n$, the positive

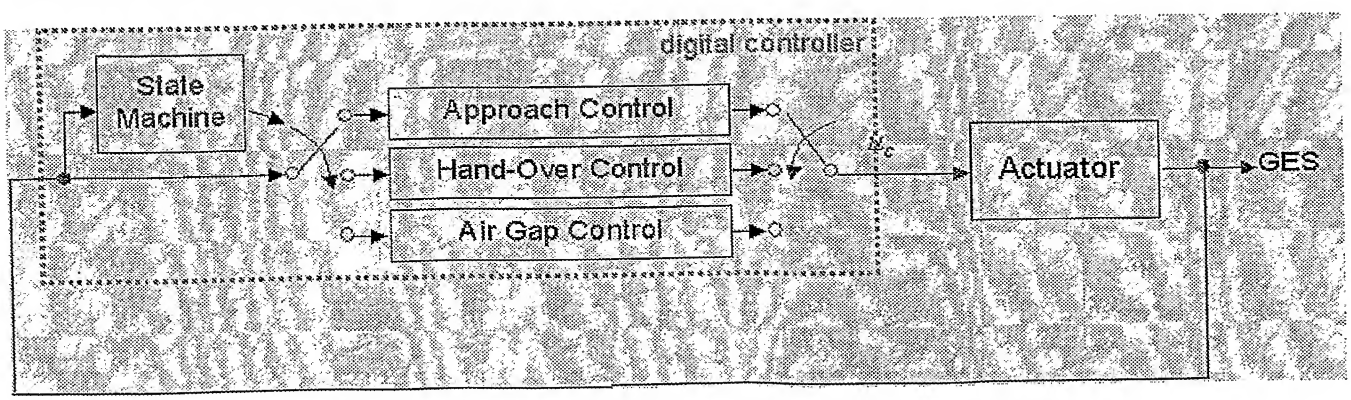


Figure 4. Air-gap servo system: mode-switching control

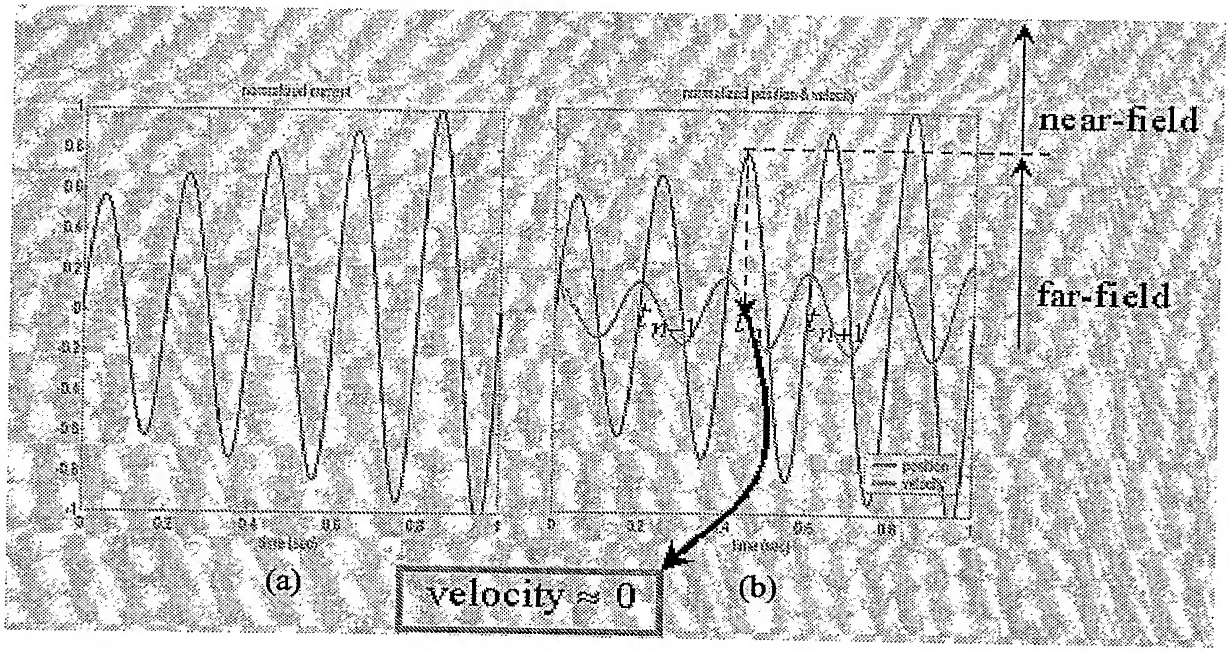


Figure 5. New approach method by sinusoidal voltage
((a) applied current for approaching (b) position & velocity during approaching)

peak position of the optical head starts to enter the near-field regime. Therefore, if the mode switching, from the open-loop approach control into the closed-loop hand-over control, occurs at $t=t_n$, the velocity of the optical head is kept zero at the switching instant. This enables us to reduce the overshoot significantly in the transient responses at the switching moment even with relatively low sampling frequency.

When the optical head moves into a near field position and the gap error signal is available, then the air gap servo system is switched into the closed-loop control operation of the hand-over control. Like in the prior art of figure 3, the gap reference for the gap servo loop is not set to its final value (Ref2), but is given by the so-called 'reference generator' shown in figure 6. Then, the transfer function representation from the target gap value Ref2 to the position output y_d of the reference generator is given by

$$Y_d(s) = \boxed{\frac{K_p^{ref}}{s^2 + K_d^{ref} s + K_p^{ref}}} \mathrm{Ref2}(s) \tag{1}$$

Thereby, the actual gap reference y_d is smoothly lowered towards its final target value Ref2. See the figure 7. Note that the settling time and the overshoot of the gap reference is determined by the gains of the reference generator.

In addition, the reference generator also provides the velocity and the acceleration reference

trajectories, v_d and a_d respectively, so that the tracking controller can be synthesized for the hand-over controller as is seen in figure 8. This way of control design method is called as 2 degree-of-freedom (DOF) control [3] because, in this case, the gains of the reference generator determines the settling time of the gap reference whereas the gains of the tracking controller determines the overshoot, or the transient behavior, at the switching instant from the open-loop into the closed-loop operation. Therefore, the two design criteria, the settling time and the overshoot, can be designed independently of each other, which is verified by simulation results in figure 9. This overcomes the drawback of the prior art mentioned in the last paragraph in page 2, and hence the pull-in performance can be improved significantly.

Figure 10 presents the schematic diagram of the final air-gap control, which is switched into operation when the GES is close to the target gap value (Ref2). It is a standard PID controller, but it can also be any other control method to regulate the air gap around the target gap.

Finally, figure 11 shows the measurement result of the transient responses from the proposed pull-in procedure. The blue and pink curves represent the GES and the reference, respectively. And, the green curve is the output of the state-machine, which determines the mode of the controller depending on the operating condition. As can be seen in the figure, the optical head can successfully settle down to the target gap of 33nm from its initial far-field position without colliding with the disc.

Therefore, the followings are the resulting claims.

- The amplitude-increasing sinusoidal signal has been applied to the actuator when the optical head approaches the near-field regime from its far-field regime. This can guarantee a zero velocity when the air-gap servo system starts its closed-loop operation. As a result, the overshoot at the switching instant can be greatly reduced with a relatively low sampling frequency.
- The 2 degree-of-freedom (DOF) control technique has been applied for the hand-over control to relax the design constraints between the overshoot and the settling time. As a result, the pull-in performance can be significantly improved.
- Figure 12 shows that, once the air gap servo is in lock, or in the closed-loop operation, then changing its gap to a different value can be done without any overshoot at all. This suggests a sort of two-step pull-in procedure to increase a safety margin against the head collision with the disc. Namely, the first target gap (33nm in the figure 11, for instance) for the hand-over control is much higher than the actually required target gap (24nm in the figure 12). Once the servo is in lock around the first target gap, then it finally moves to the final required target gap in a safe way.

3. Remarks

The key to the sinusoidal excitation for the approach control is to modulate an increasing signal, which is a ramp signal in the case of the figure 5, with a sinusoidal signal to guarantee that the optical head velocity is zero or very small when the head reaches the near-field regime. Under this same rationale, the actual implementation can be slightly different as can be presented in the figure 13 (a)-(b). Yet another possibility is presented in the figure 13(c), in which a low-pass filtered staircase signal is applied to the actuator.

Note the practical consideration that, in all of the embodiments, the frequency of the excitation input signal should be chosen well below the resonance frequency of the underlying actuator to avoid the undesirable resonant oscillation during the approach control. Furthermore, the increment of the actuator position, which is for instance denoted by Δy in the figure 13 (a), should be smaller than the GES linear range.

4. References

[1] T. Ishimoto, K. Saito, T. Kondo, A. Nakaoki and M. Yamamoto, "Gap Servo System for a Biaxial Device Using an Optical Gap Signal in a Near Field Readout System," ISOM/ODS 2002

[2] T. Yamaguchi, H. Numasato, and H. Hirai, "A Mode-Switching Control for Motion Control and Its Application to Disk Drives: Design of Optimal Mode-Switching Conditions," *IEEE Trans. Mechatronics*, pp.202-209, Sep. 1998.

[3] G. Franklin, J. Powell, and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 4th Ed. Prentice-Hall, 2002

[4] K. Saito, et. al, "Readout Method for Read Only Memory Signal and Air Gap Control Signal in a Near Field Optical Disc System," Jpn. J. Appl. Phys. Vol. 41, pp.1898-1902, 2002

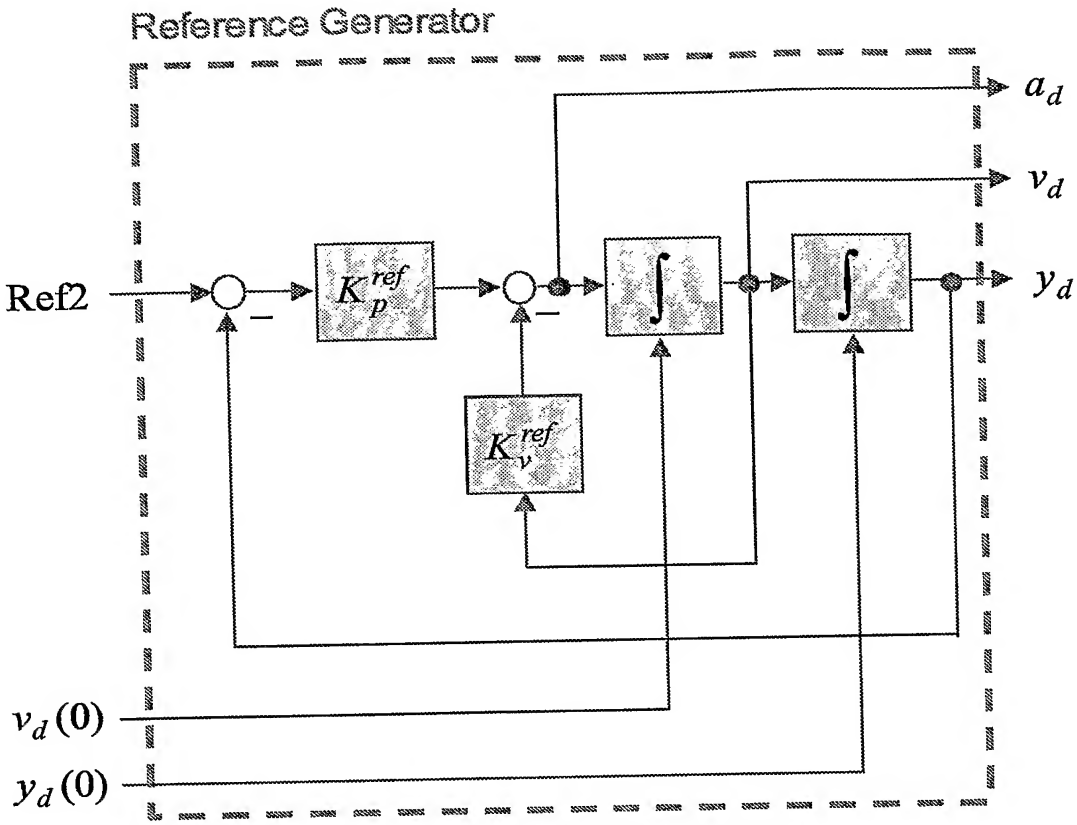


Figure 6. Reference generator

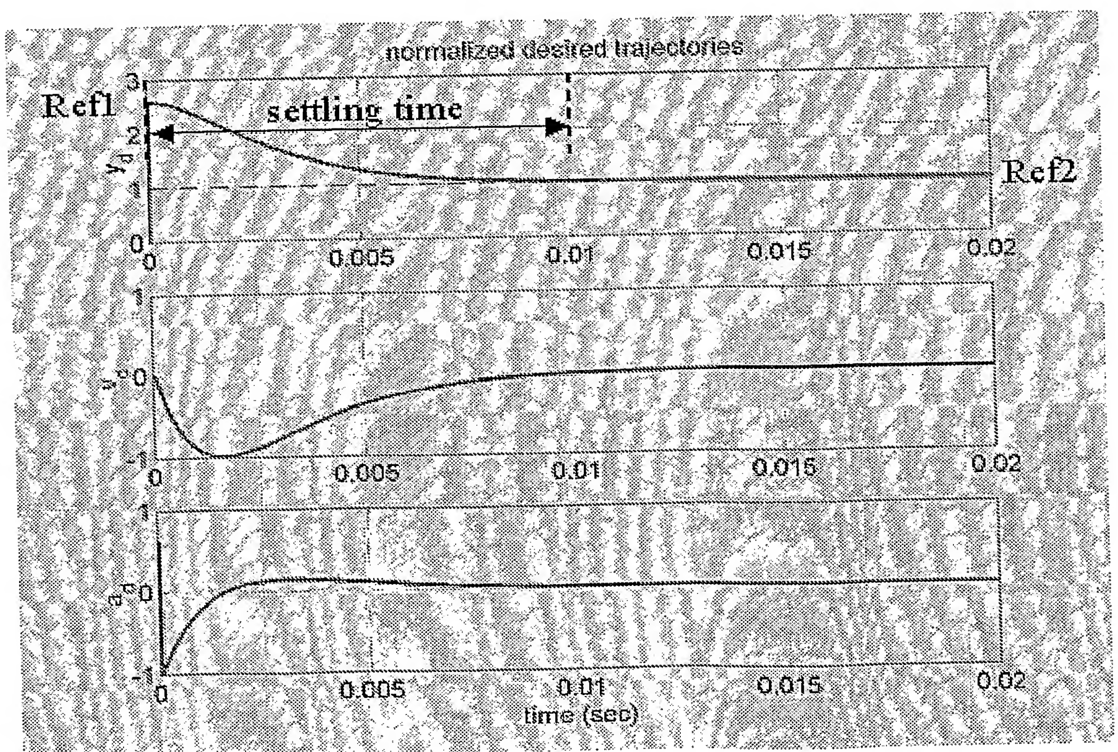


Figure 7. Reference trajectories

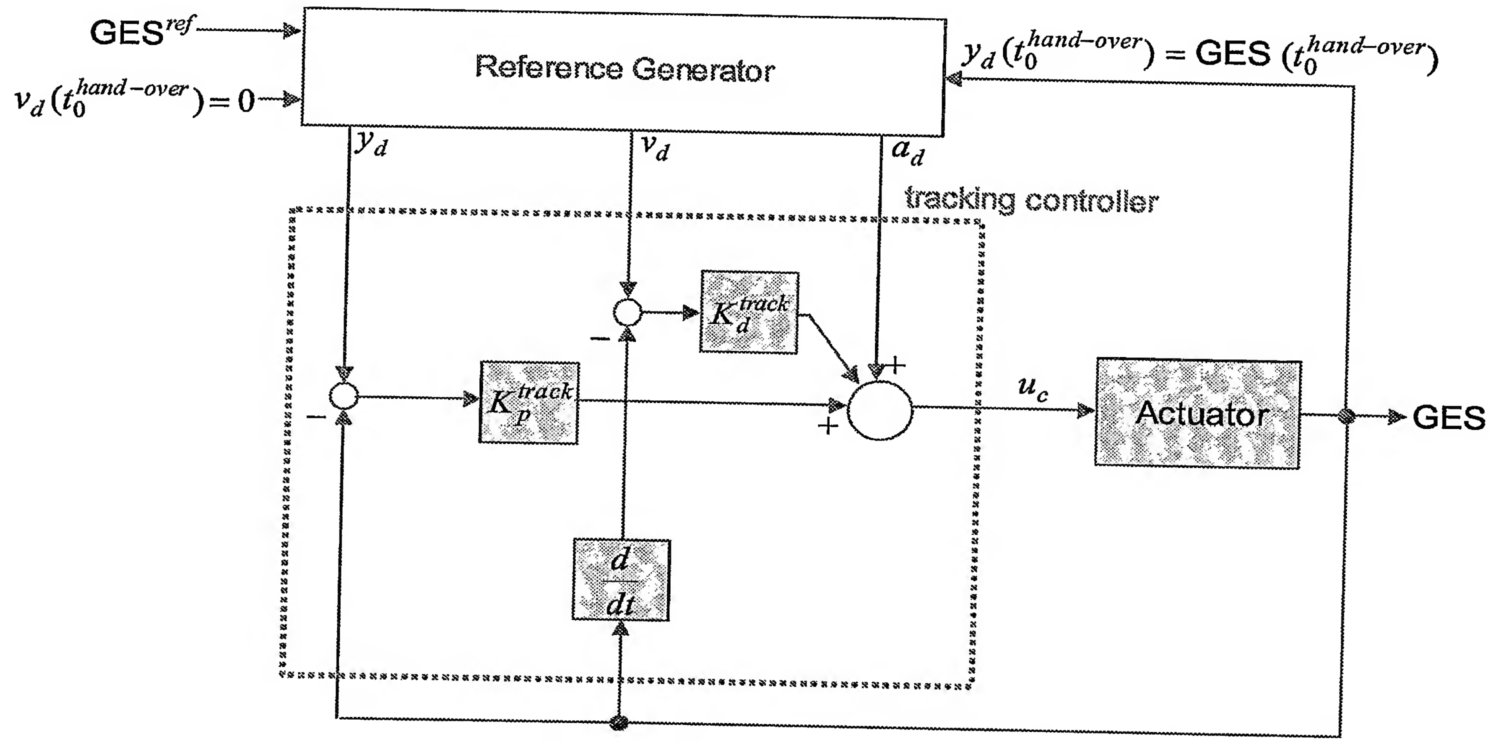
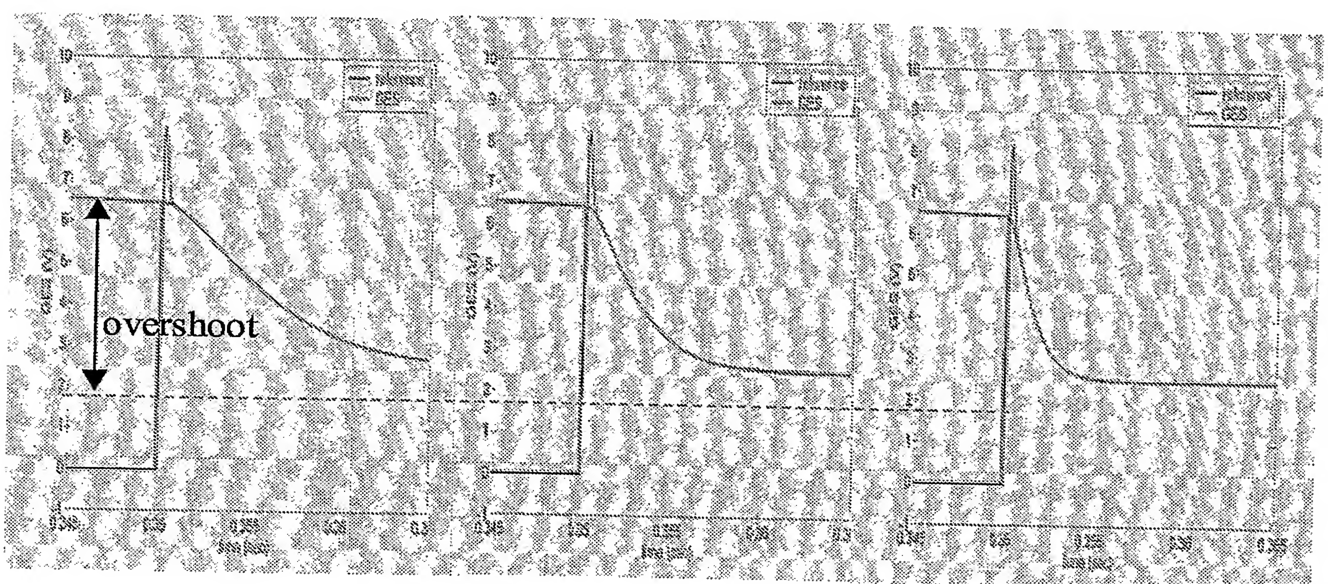


Figure 8. Schematic diagram of the hand-over controller: 2 DOF control



(a) (b) (c)

Figure 9. Simulated pull-in responses for various reference trajectories with different settling times of (a) 20msec (b) 10msec (c) 5msec

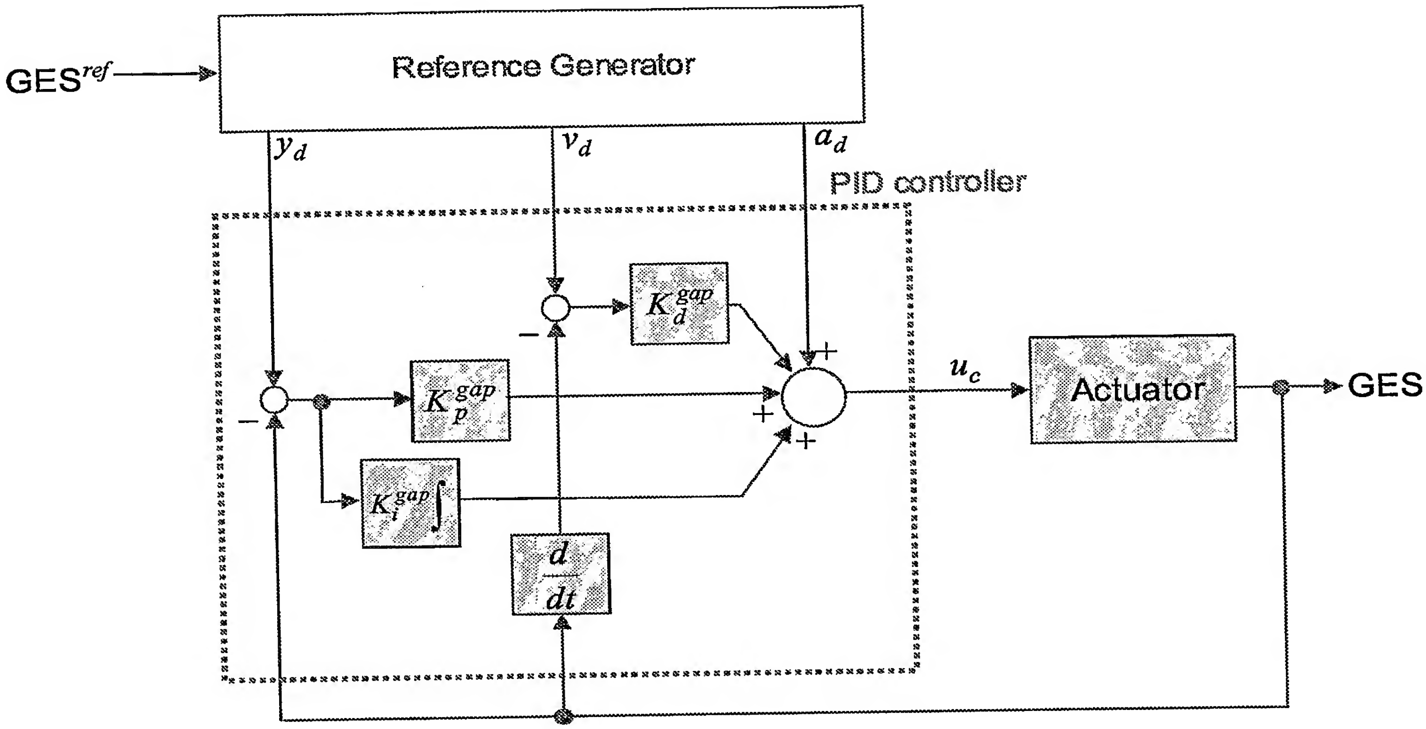


Figure 10. Air-gap controller

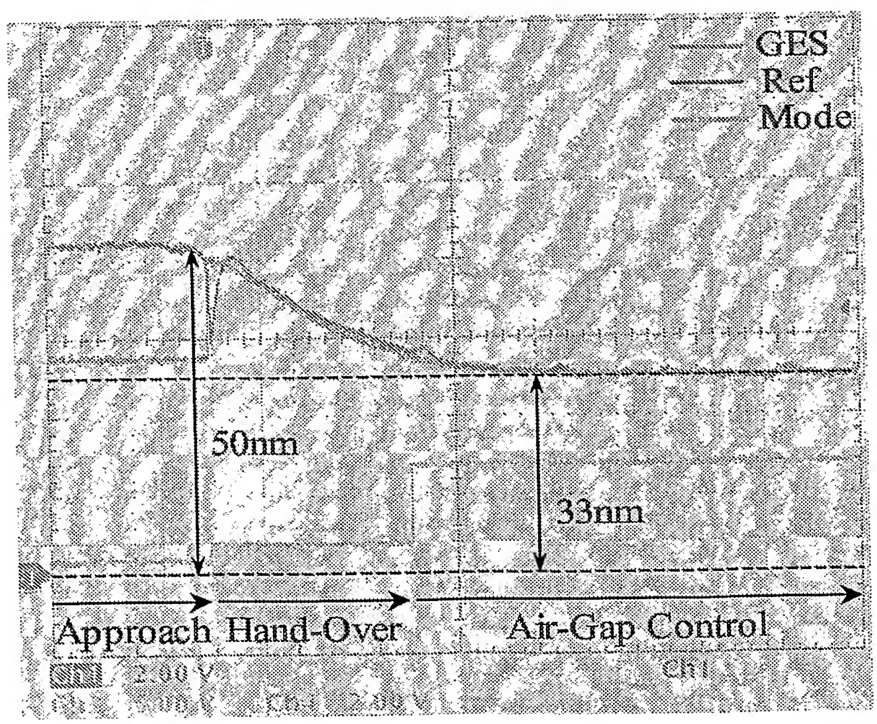


Figure 11. Measurement of transient responses during the new pull-in procedure

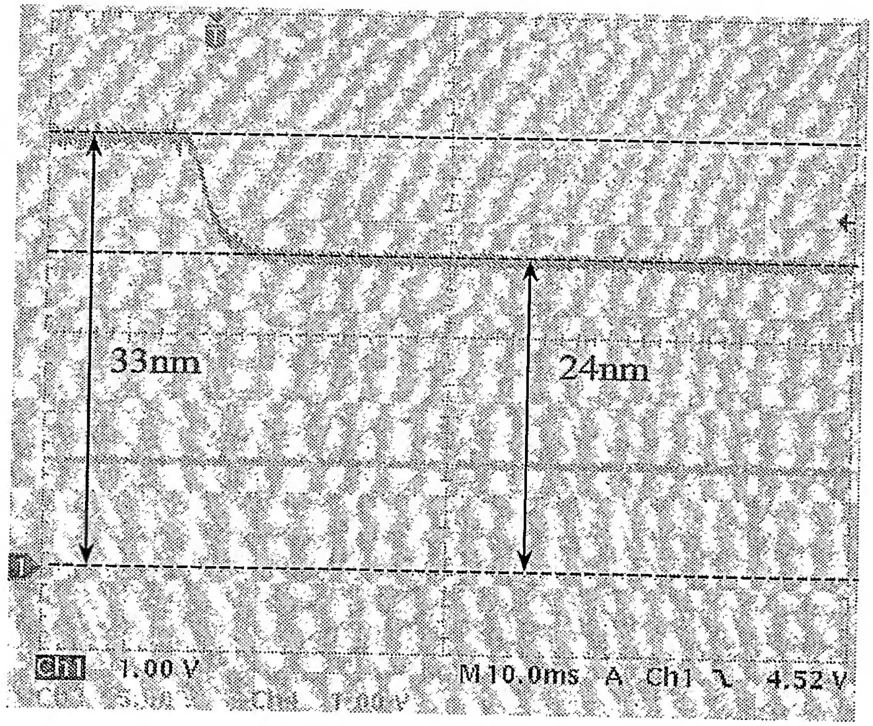


Figure 12. Measurement of transient responses during the servo is in closed-loop operation

Appendix A

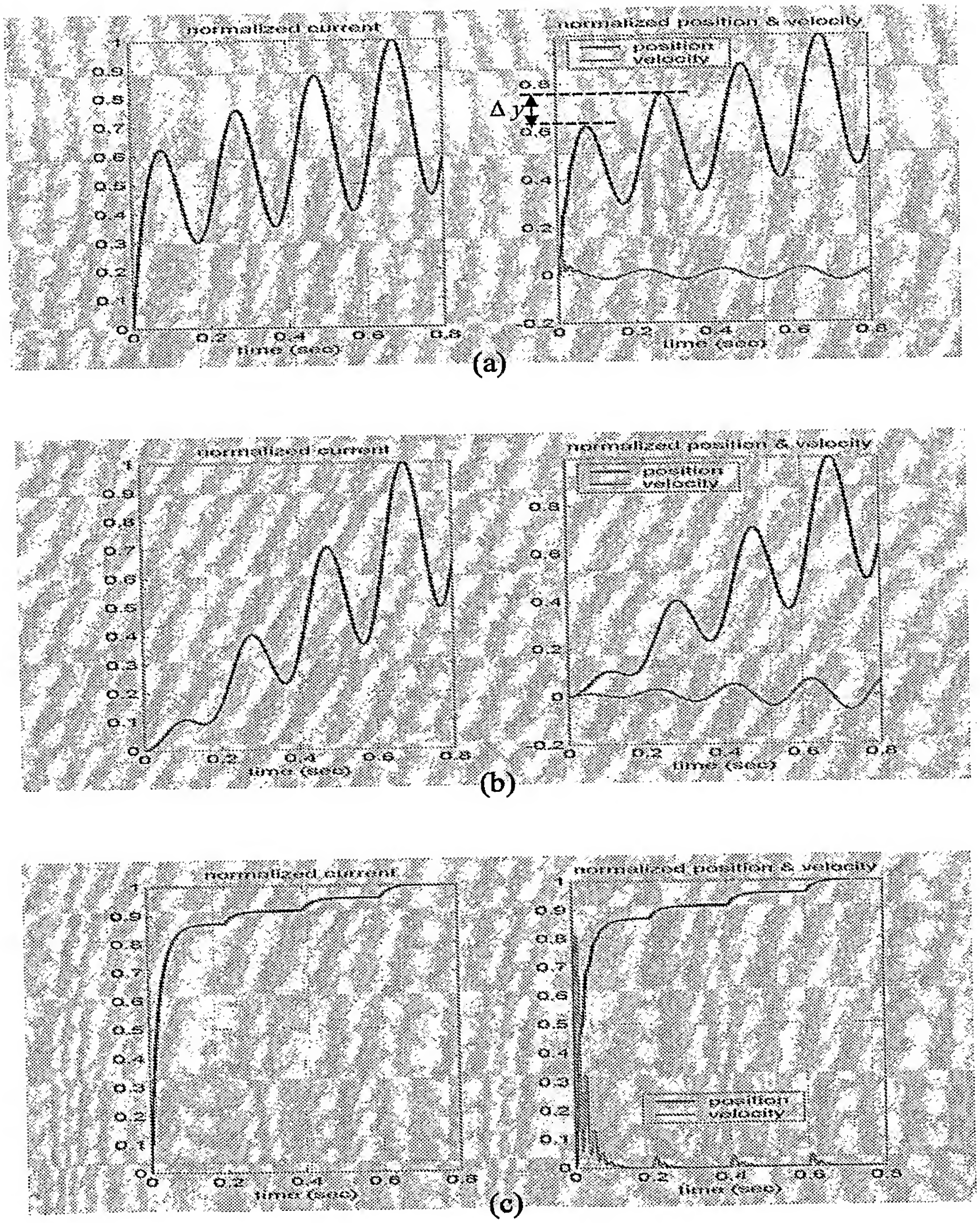


Figure 13. Another new approach method
((a) Modulate a ramp signal with a sinusoidal signal with an offset;
(b) Modulate an increasing part of a sinewave with a sinusoidal with an offset;
(c) Staircase signal filtered by a low-pass filter)

Gap servo system for a biaxial device using an optical gap signal in a near field readout system

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1. Introduction

A readout method using a near field optical head, which consists of an aspherical lens and a Solid Immersion Lens (SIL), has been proposed as a technology to read out 30Gbytes or more on a 12cm disc. In the system, it is necessary to maintain an air gap between the SIL bottom surface and the disc surface constantly in a near field position where the evanescent wave is detectable.

For this purpose, we have developed the gap servo system using a piezo-transducer (PZT) as an optical head drive device [1]. The gap servo system with the PZT creates a stable near field state easily, but it requires a high control voltage and a large optical head device. Hence it may not be practical for a near field system.

Conversely, an optical head with a biaxial device is considered to be the most promising device for a practical optical disc system. However, since it has a long working range of hundreds of micrometers and high voltage sensitivity, a new technique is required for applying a gap servo in a near field system. In particular, the overshoot upon starting a gap servo is a severe problem. An overshoot of less than one micron is considered a trivial problem for a far field optical system, but it could cause a collision of the optical head in a near field system.

In this paper, we report on a gap servo technique with a biaxial device in a near field readout system that suppresses the overshoot at the beginning of the gap servo.

2. Optical gap servo loop

Fig.1 shows a schematic diagram of our gap servo system. We used a blue laser diode of 405nm wavelength as a light source and a near field optical system. The near field optical head consists of a 0.43-NA aspherical lens and a SIL with a refractive index of 1.8, which result in a combined 1.4-effective NA. The gap servo error is detected as the portion of the total reflected power from the bottom surface of the SIL with polarization orthogonal to that of the incident light [2]. The error signal is converted into a digital signal after normalization, and is input into the gap servo block. After the optical head is moved from the far field position into the near field position by the pull-in procedure, the gap servo loop starts to operate. The servo signal is converted into an analog signal and controls the biaxial device in order to keep the air gap constant.

According to the design specification of the gap servo, the allowance of the disc surface deviation is 10um (p.p.) and that of the remaining gap error is within ±1.0nm. Fig.2. shows the observed frequency characteristics of the gap servo loop. As shown in Fig.2, the cutoff frequency is 2.5 kHz, the gain margin is 10dB and the phase margin is 34deg. This result shows close agreement with the theoretical value. Also, applying the gap servo to a disc with surface deviation of 8.1um in order to control the air gap of 100nm, the remaining gap error was below ±1nm. From the result, we confirmed the gap servo system satisfies the specification of the gap servo loop.

3. Pull-in procedure for the optical gap servo

In the optical gap servo of our near field readout system, the gap error is detected within a near field regime of approximately only 200nm. Therefore, by a pull-in procedure, the optical head must be moved from the initial far field position into the near field position before the gap servo loop starts to operate. If the gap servo loop starts to operate right away without a pull-in procedure, the optical head collides with the disc due to the overshoot at the beginning of the gap servo loop as shown in Fig.3. In this experiment, the initial far field position was set to 300um based on the specification of the biaxial device and the target gap length was set to 100nm over

the disc. This corresponds to the control by which the total reflected power is set from 1V to 0.6V [1]. In this section we discuss the way of the pull-in procedure.

Considering the focus servo for an ordinary optical disc, the focus error is detected as the S curve caused when a biaxial device is shifted up and down. The focus servo loop starts to operate when both a zero crossing point of the S curve and the pull-in signal is detected. It is possible for the gap servo loop to start operation by a similar idea to the far field focus servo. In the case of the gap servo, a ramp input is impressed to the biaxial device in order to make the optical head approach the disc at a constant speed and switch to the gap servo loop when the optical head moves into a near field position. Applying this method, the optical head could still collide with the disc by an overshoot of 100nm or more during the gap servo operation if the target gap length is set to 100nm. Fig.4 (a) shows the relation between the optical head approaching speed and the overshoot when applying this technique to the pull-in procedure. Adopting the criterion that the overshoot allowance in the gap servo loop is 95% of the target gap length which is equivalent to 95nm in our case, the optical head approaching speed is kept below approximately 1mm/sec. Fig.4 (b) shows the simulated total reflected power when the optical head approaching speed is set to 1mm/sec. By using this setting, the settling time, which is the time from the start of the ramp input until the head settles to within ±1% of the target gap length, is only 313msec. Even though the optical head does not collide with the disc, the collision allowance for the optical head with the disc is only approximately 5nm. The wider the collision allowance is, the more preferable the system is for a reliable near field readout system. Judging from Fig4. (a), a wider collision allowance could be realized by using a slower approaching speed. However, the slower the optical head approaching speed is, the longer the settling time is. Therefore, this low-speed approaching method is not practical for achieving a wider collision allowance. So it is desirable to realize a pull-in method with a fast settling time at such as 1mm/sec and a wider collision allowance.

This can be realized with the "Pull-in procedure" shown in Fig.5. In this procedure, the input signal is the total reflected power. The near field position is judged by "Near field detector" which detects the time of t1 when the reflected power is below the level of the far field power level by using a threshold of "Ref1". In the far field position, a ramp voltage is generated by the "Approach voltage generator" and applied until the optical head moves to the near field position which is equivalent to a 200nm-air gap. The optical head approach velocity (Vapc) is set as 1mm/sec. At the time of t1, the optical head approach is stopped and held, and then the gap servo loop starts to operate. In the gap servo loop, the gap reference is set to not the final target of "Ref2", but it is gradually lowered from the total reflected power level of "Ref1" at the time of t1 to the gap target of "Ref2" at the time of t2. Fig6 (a) shows the simulation result of the relation between the rate of change of the reference from "Ref1" to "Ref2" (Rref) and the overshoot and the settling time when Vapc is 1mm/sec. When Rref is 0.1V/sec, the overshoot is suppressed completely and the settling time is minimal. Fig.6 (b) shows the simulated total reflected power when the gap servo is operated by using the "Pull-in procedure" when Vapc is 1mm/sec and Rref is 0.1V/sec. As shown in Fig.6 (b), the settling time is only 314msec and the overshoot is completely suppressed. We have succeeded in automatically controlling the air gap from the far field position of 300nm to the near field position of 100nm at a high speed and the collision allowance can be more than 100nm which is equivalent to the gap target.

Fig.7 shows the readout signal of a 30Gbyte ROM disc when the air gap is controlled to 100nm by our gap servo system and tracking is performed by the 3-beam method. As shown in Fig.7, the modulation ratio (minimum/maximum RF amplitude) is approximately 55%. This result almost corresponds to the theoretical value (52%) from the MTF curve for 1.4-NA. We realized a 1.4-NA near field readout system with a biaxial device using our optical gap servo technique.

4. Conclusion

We have developed an optical gap servo system for a near field system with a biaxial device. By using our gap servo technique, we have been successful in controlling the air gap from a far field position of 300nm to a near field position of 100nm with a short settling time without overshoot. The authors acknowledge the indispensable support in this work for T.Kubo, H.Tanase, M.Furuki, S.Masuhara and S.Kobayashi.

References

[1] Tsutomu Ishimoto et al, Near field readout system for a high density optical ROM disc, ODS 2001 proceedings Vol. 4342, pp294-303

[2] Kimihiro Saito et al, Readout Method for ROM signal and Air Gap Control signal in a Near Field System, ISOM01 Fr-N-06

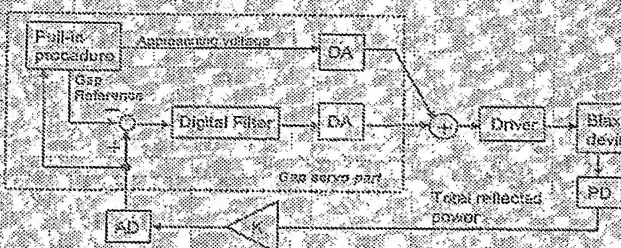


Fig.1 Gap servo block diagram

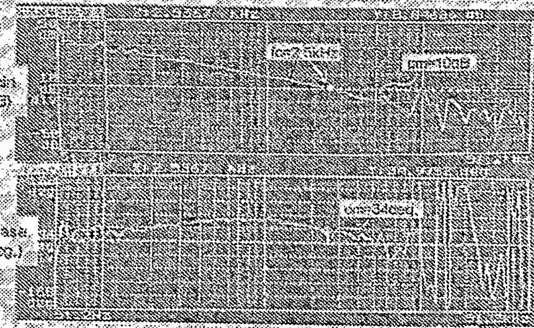


Fig.2 Bode plot of the gap servo loop

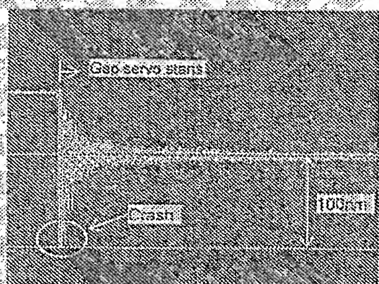
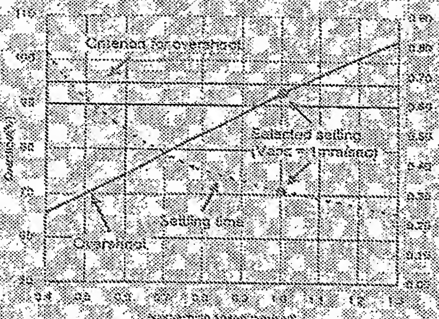
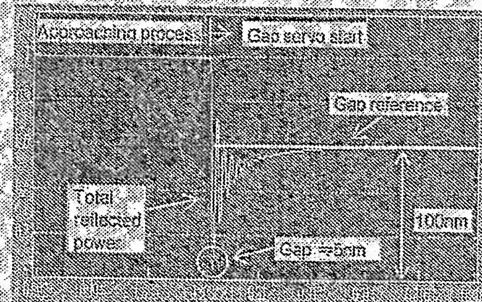


Fig.3 Appling gap servo loop only



(a) Head Approach speed vs. Overshoot and settling time



(b) Gap servo operation (Vapc = 1mm/sec)

Fig.4 Relation between head approaching speed and overshoot

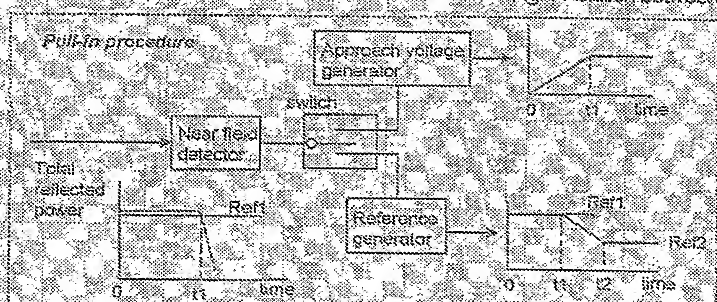


Fig.5 Pull-in procedure block diagram

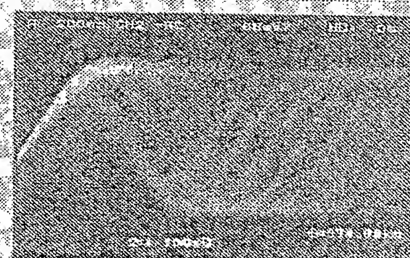
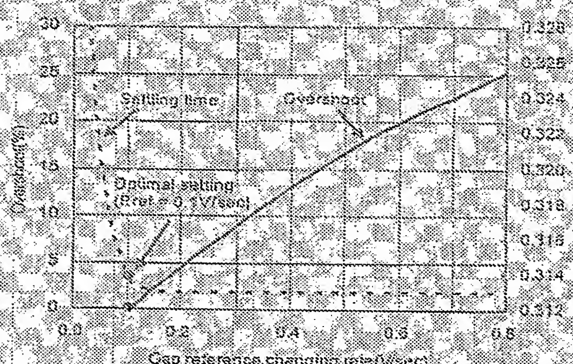
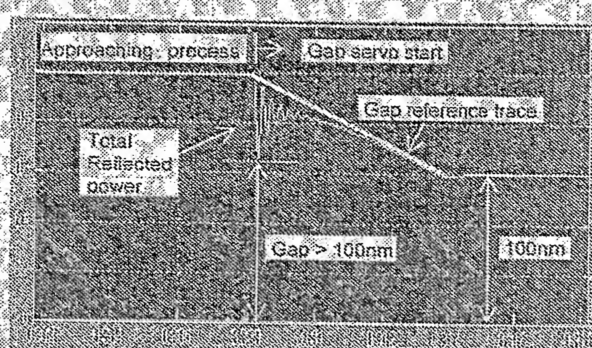


Fig.7 Near field readout signal of 30Gbyte ROM disc
(Applying tracking servo)



(a) Ref. changing rate vs. Overshoot and Settling time (Vapc = 1.0mm/sec)



(b) Gap servo operation (Vapc = 1mm/sec, Rref = 0.1V/s)

Fig.6 Gap servo with pull-in procedure

CLAIMS:

1. A pull-in method in an air gap servo system for optical recording, substantially as shown and described in the above detailed description and figures.

2. A pull-in method as claimed in claim 1, wherein said optical recording is near-field optical recording.

3. A pull-in method as claimed in claim 2, wherein said air gap servo system comprises an optical head and an actuator for actuating the optical head, applying an amplitude-increasing sinusoidal signal to the actuator when the optical head approaches a near-field state from a far-field state.

4. An optical recording device with an air gap servo system for optical recording, substantially as shown and described in the above detailed description and figures.

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